A Fast Data Simulator for High Density Perpendicular Recording

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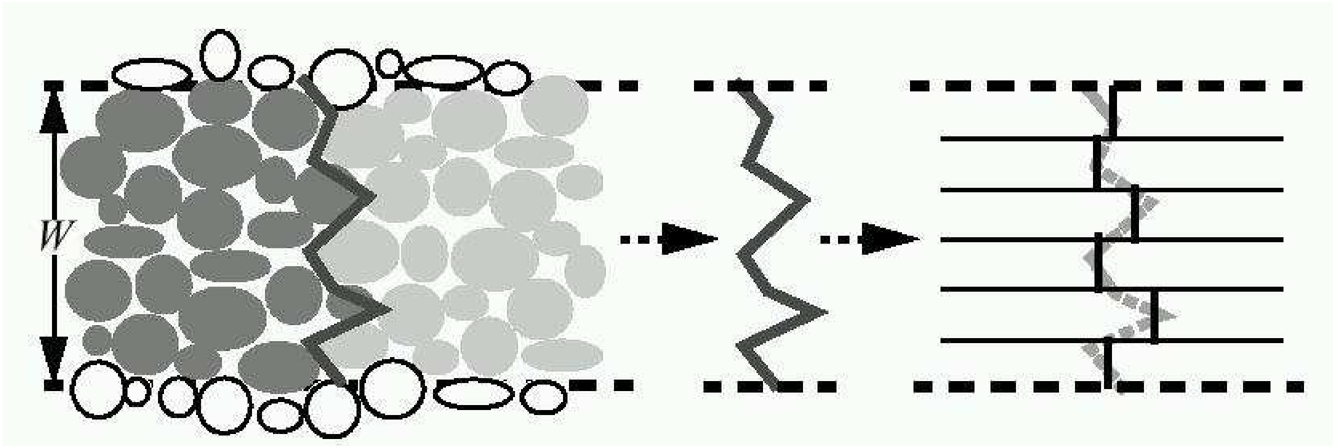
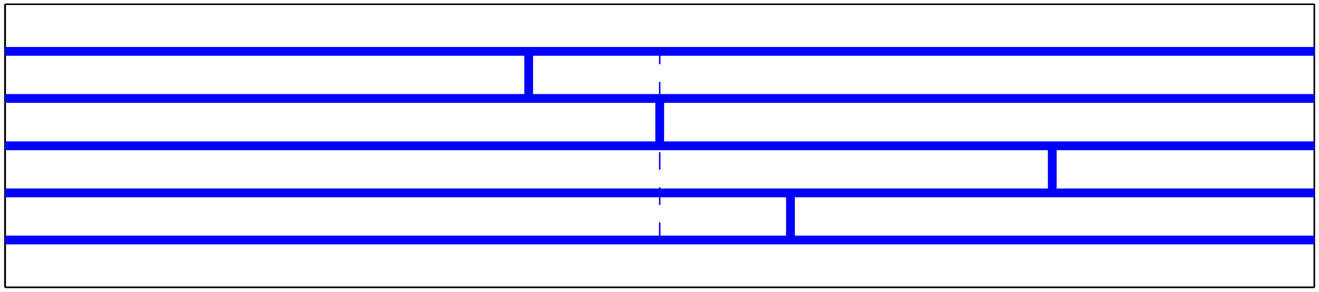
Transition noise in recording



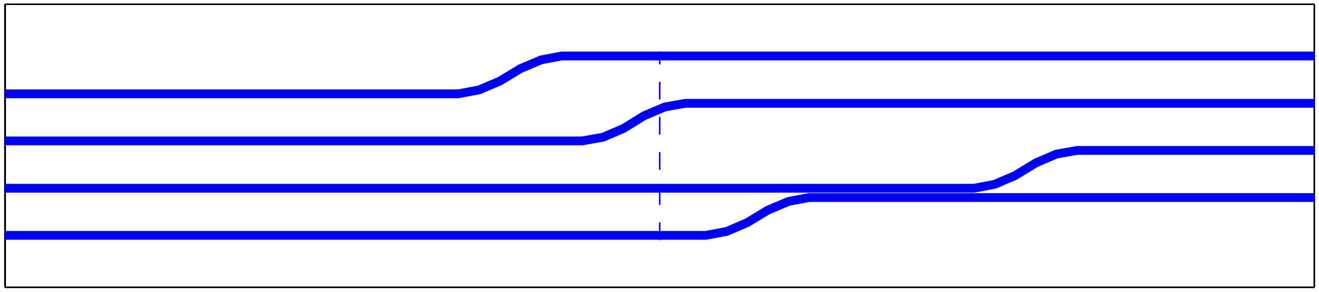
- A major source of distortion in perpendicular recording is transition noise just as in longitudinal recording.
- The cause of transition noise is the granular structure of the recording media.
- To account for transition noise, the microtrack model [Caroselli and Wolf] is used.
- Divide one recording track into smaller microtracks each with a random shift.

The microtrack model

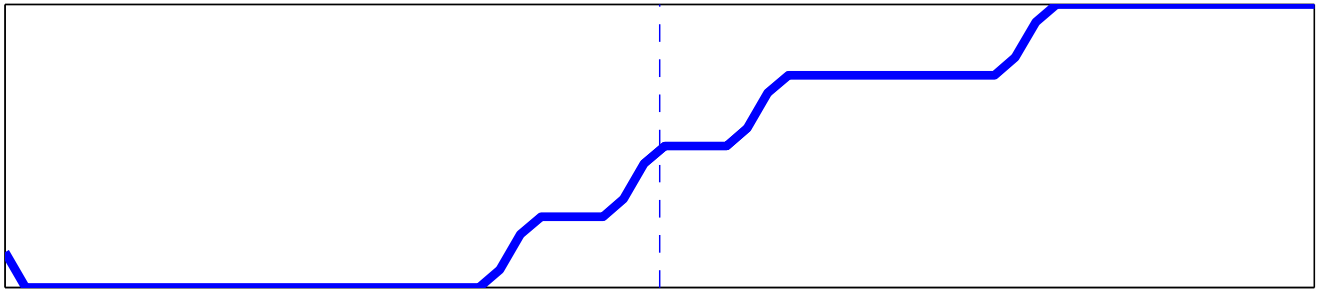
Microtrack Transition Positions



Microtrack Transition Responses



Microtrack Output Waveform



The microtrack model (cont.)

- Sum delta-functions and convolve with long response once.

$$
\begin{aligned}
s(t) &= \frac{1}{N_t}\sum_k \sum_i a_k \cdot h(t - kT - \tau_{i,k}) \\
&= \underbrace{\left[\frac{1}{N_t}\sum_k \sum_i a_k \cdot \delta(t - kT - \tau_{i,k})\right]}_{r(t)} \otimes h(t)
\end{aligned}
$$

- The τ's are obtained from a CDF derived from the average magnetization transition profile:

$$
P(x \leq \tau) = \frac{1}{2}\left(1 + \tanh\left(\frac{2\tau}{\pi a}\right)\right)
$$

- Define: N_t - number of microtracks, l_h- length of $h(t)$, and X_s- oversampling rate.
- Original microtrack model: $\mathbf{N_t \cdot l_h \cdot X_s}$ operations per bit.
- Convolve once approach: $\mathbf{N_t + l_h \cdot X_s}$ operations per bit.

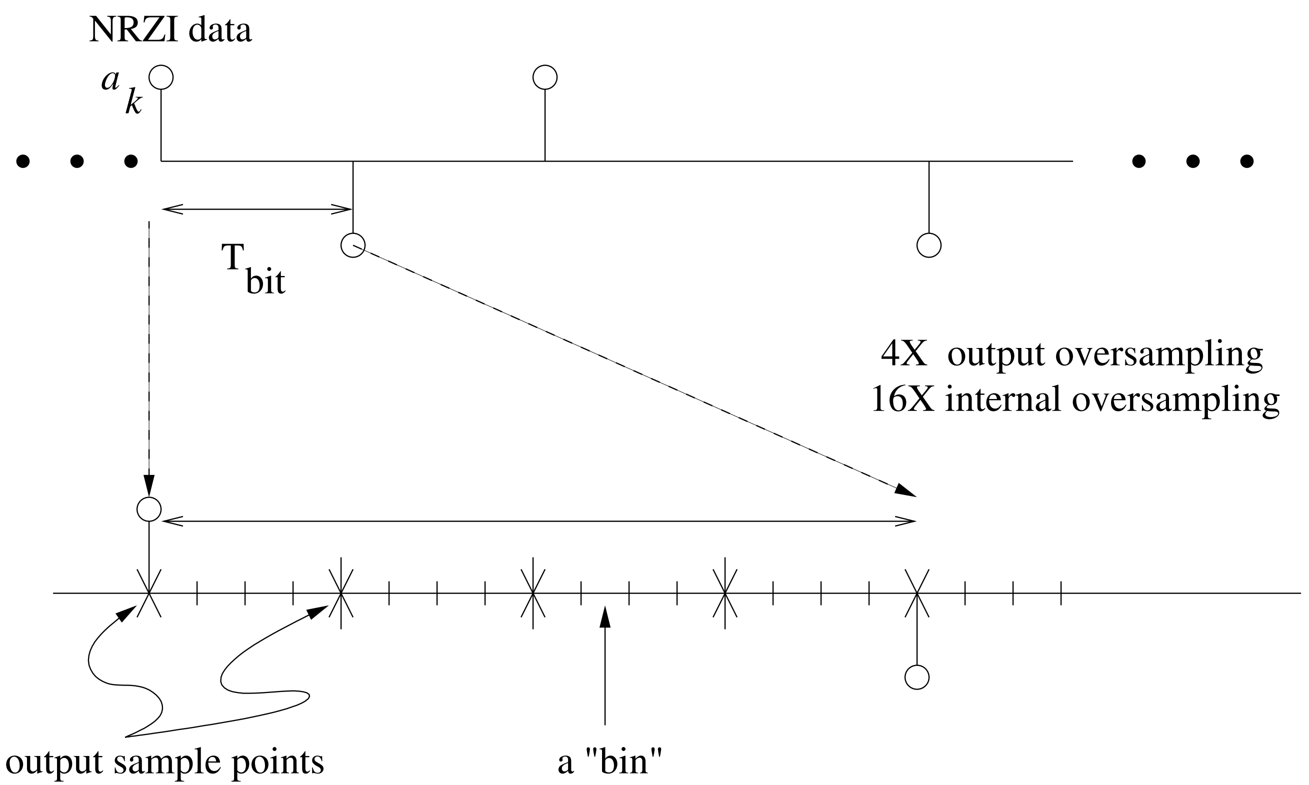
Model architecture and the simulator flow

- To describe the simulator exactly, its flow can be broken down into 4 steps:

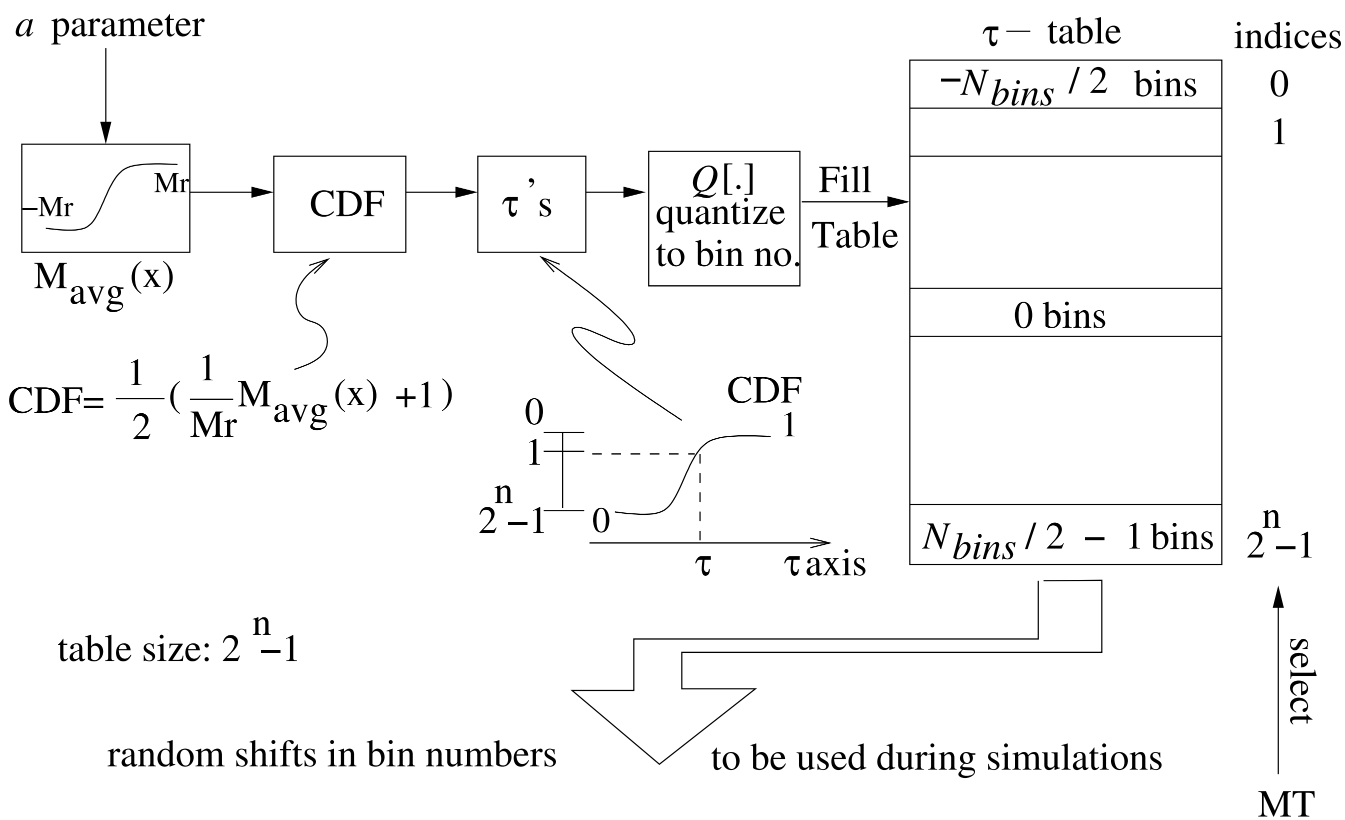
1. Create a table of random shifts or the τ-table.
2. Generate Uniform Random Numbers (URNs) to index into the τ-table.
3. Shift the impulses and sum to form $r(t)$.
4. Convolve $r(t)$ with $h(t)$ to reconstruct $s(t)$.

Oversampling by "binning"

- The response $h(t)$ and hence, $s(t)$ are sampled by the simulator.
- To minimize aliasing, internal oversampling is performed by partitioning the period in between two output waveform samples into discrete "bins."

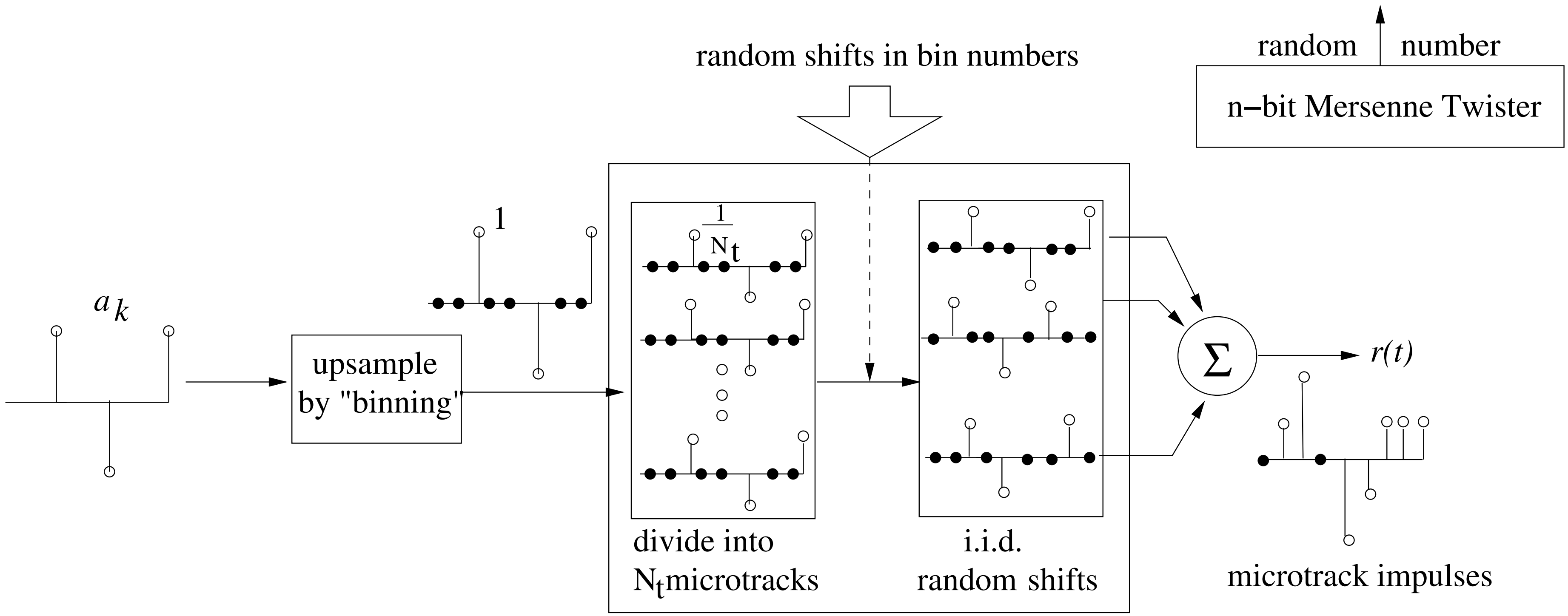


Step 1 and 2: Creating the τ-table and generating URNs



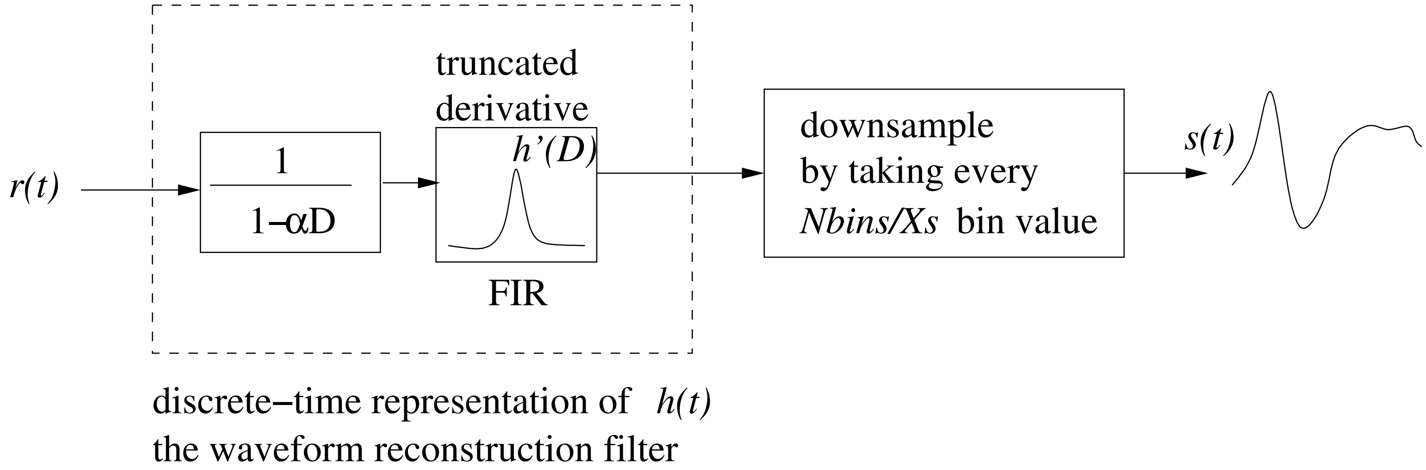
- The random τ shifts are quantized and stored as bin numbers.
- The Mersenne Twister random number generator is used during simulation to produce random indices to pick out the random shifts in bin numbers.

Step 3: Generating the microtrack impulses $r(t)$



- Assign the impulses to bins according to the random bin numbers and sum to obtain $r(t)$.

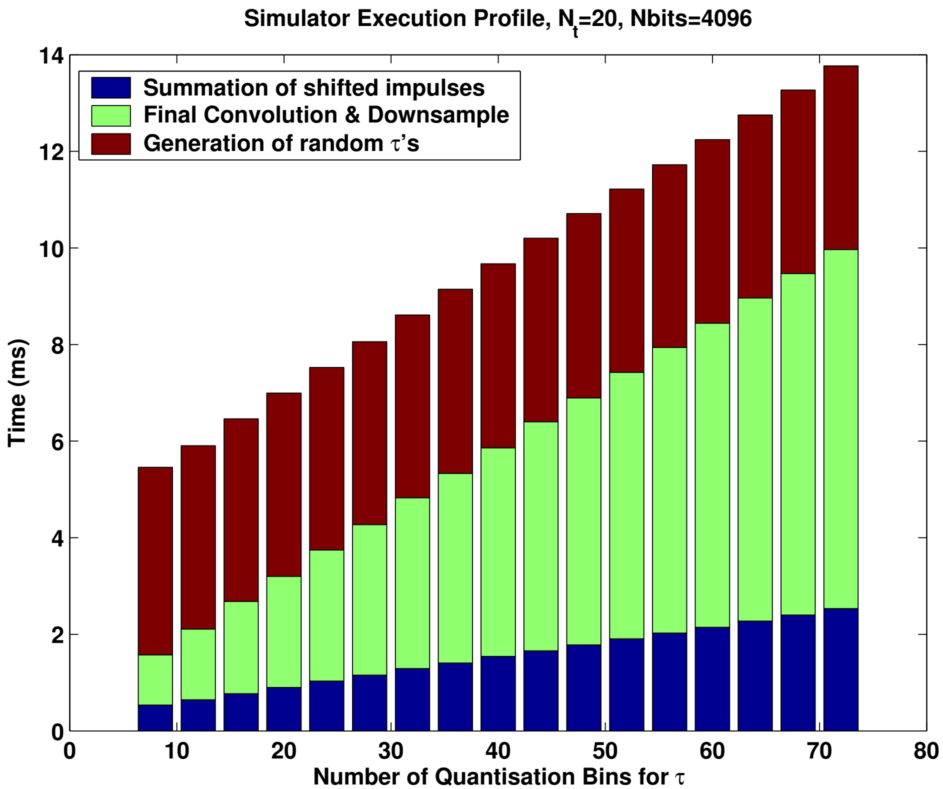
Step 4: Reconstructing the output waveform $s(t)$

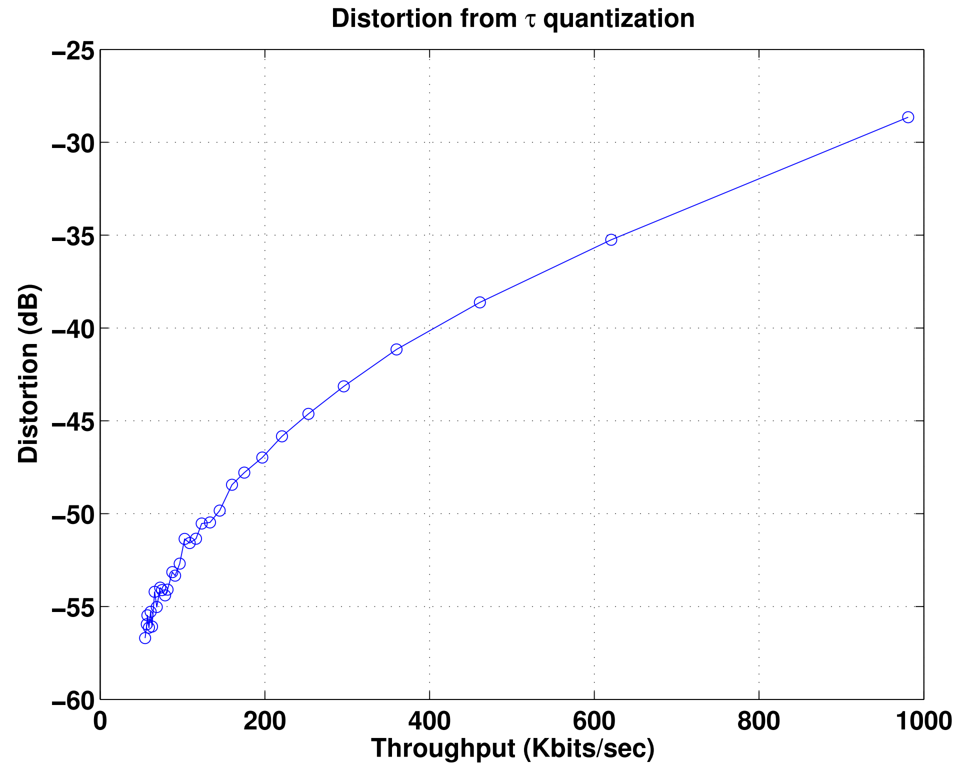


- The output waveform $s(t)$ is obtained by convolving $r(t)$ with $h(t)$.

- Can partition the discrete-time representation of $h(t)$ into the product of an accumulator and its shortened derivative $h'(D)$ to increase simulation speed.

Effects of τ-quantization: throughput vs. distortion



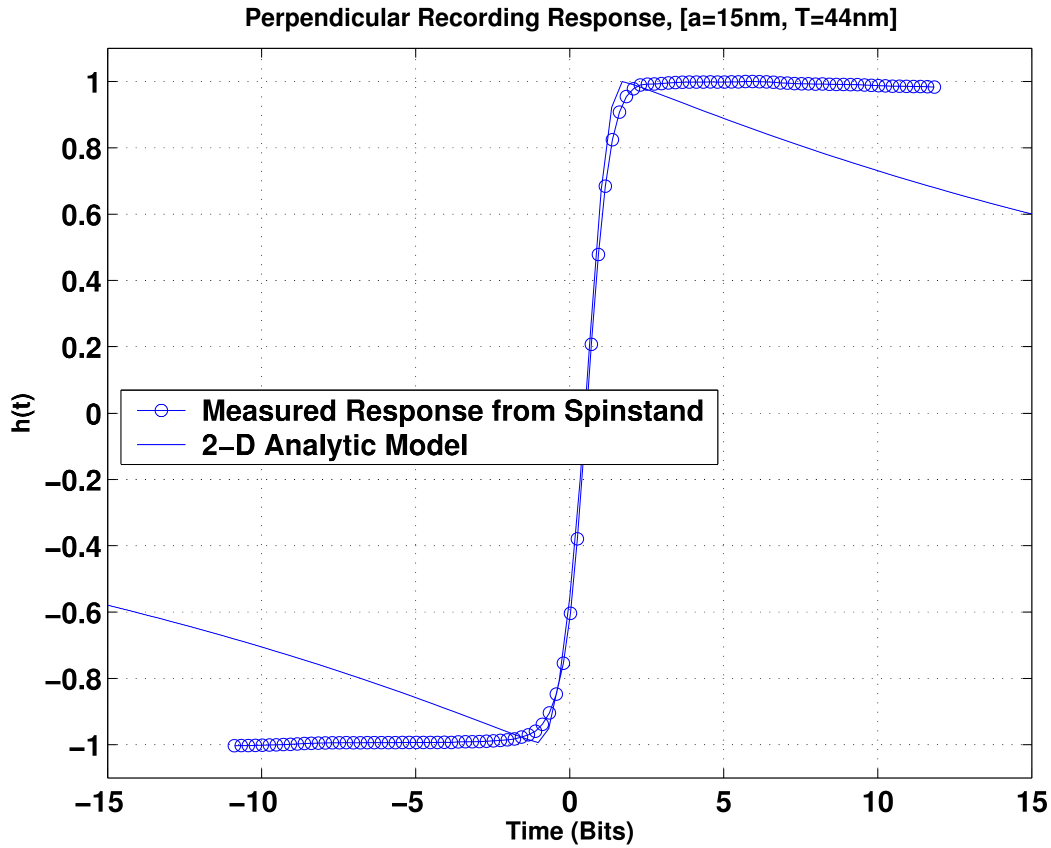


- The distortion at a throughput of more than 1 Mbps is still small.

Simulator speed enhancement via response shortening

- Consider the final waveform reconstruction filter:

$$
\begin{aligned}
h(D) &= \frac{1-D}{1-D} h(D) \\
&= \frac{h'(D)}{1-D} \\
&\approx \frac{W\left[h'(D)\right]}{1-D}
\end{aligned}
$$

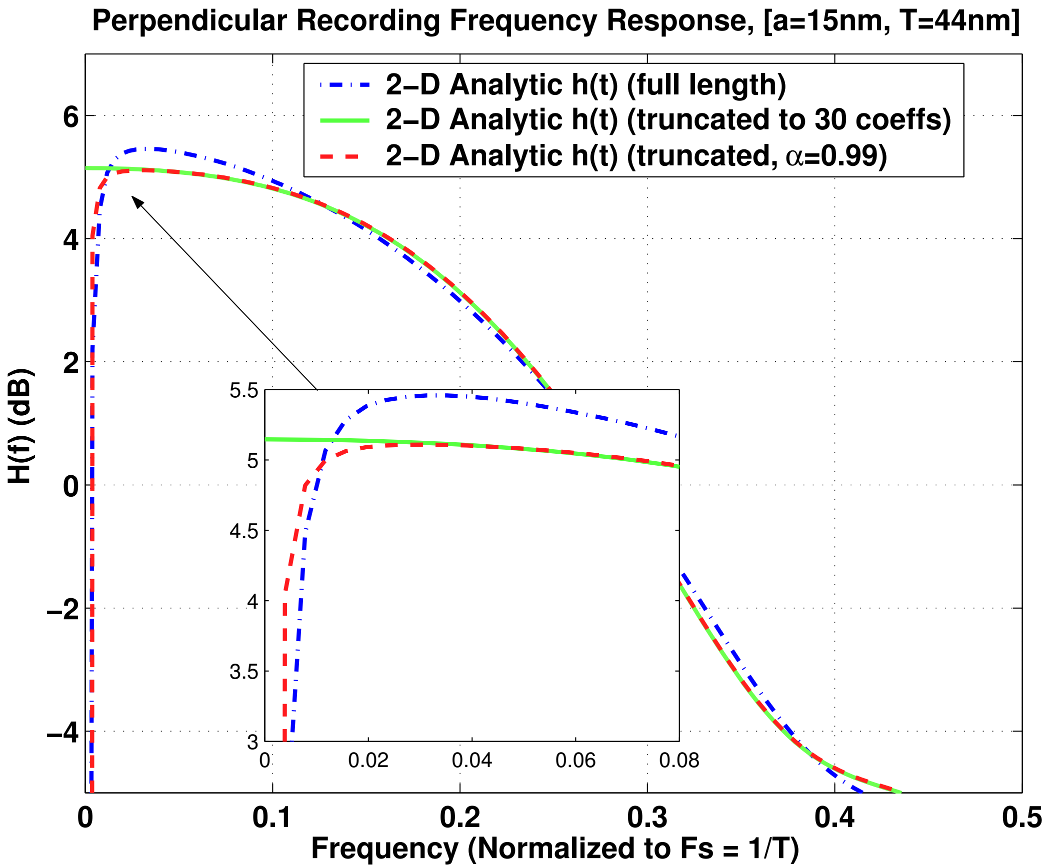


- The IIR filter has much fewer taps.

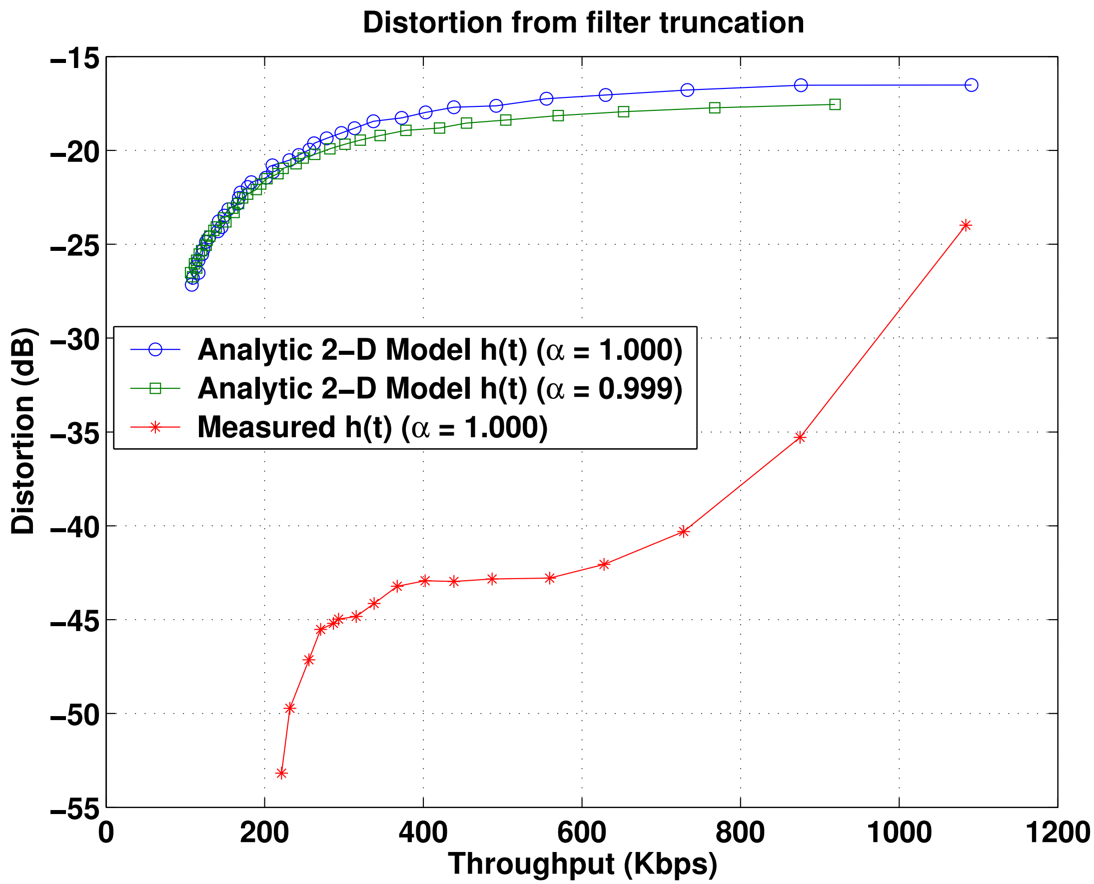
Distortion reduction via response matching

- Windowing $h'(D)$ removes the notch at DC in its frequency response.
- The distortion error is reduced by further filtering with a high-pass filter, thus re-introducing the notch at DC.

$$h_\alpha(D) = \frac{1-D}{1-\alpha D} \cdot \frac{W\left[h'(D)\right]}{1-D} = \frac{W\left[h'(D)\right]}{1-\alpha D}$$



Distortion and throughput profile with response shortening



- The improved response matching reduces distortion.
- Redundant computations in the final filtering and decimation can be eliminated by computing one in every N_{bin}/X_s samples.

Other noise effects

- By accounting for other noise effects, a more realistic waveform $s\left(t\right)$ can be produced.
- Non-uniform track width: weighting the microtracks by a profile w_k
- Track edge curvature: shifting the transitions by a track curvature profile c_k
- DC noise as AWGN

$$s\left(t\right)=\sum_{k=0}^{L-1}\frac{a_k w_k}{N_t}\sum_{i=0}^{N_t-1}h\left(t-kT-\tau_{i,k}+c_k\right)+n_{DC}(t).$$

Summary

- Presented a waveform simulator for perpendicular recording based on the microtrack model.
- Performance and distortion tradeoffs were quantified.
- A throughput of more than 1 Mbps can be achieved on a contemporary desktop computer with negligible distortion.
- Other noise sources can also be incorporated to further increase the accuracy of the generated waveform.

References

1. J. P. Caroselli and J. K. Wolf, “Applications of a new simulation model for media noise limited magnetic recording channels,” *IEEE Trans. Magn.*, vol. 32, pp. 3917-3919, Sept. 1996.

2. J. P. Caroselli, *Modeling, Analysis, and Mitigation of Medium Noise in Thin Film Magnetic Recording Channels.* Ph.D. Thesis, University of California, San Diego, 1998.